WERE CM CHONDRITES AQUEOUSLY ALTERED IN THE QUIESCENT INTERIOR OF THEIR PARENT BODY?

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Introduction and Summary:

Neither the internal structure nor the formational history of the CM asteroidal parent body(s) has been established. Several lines of evidence-including their irradiation record [1], brecciated appearance, and extrapolated thermal history [2]-suggest that CM materials might sample a relatively thin asteroidal regolith that was subjected to both aqueous alteration and periodic episodes of mechanical mixing by impacts. On the other hand, we present petrologic observations here, mostly of delicate aqueous alteration features, that are more easily reconciled with an alternative scenario-that CM materials were aqueously altered at depth in the CM asteroidal parent body after brecciation and that they remained in this unenergetic environment throughout the compaction and lithification process. If true, this implies that: a) the observed brecciation of CM chondrites occurred very early, prior to aqueous alteration and perhaps during accretion itself and, b) the irradiation record of CM chondrites may best be explained by an enhanced particle flux in the early solar system. Observations were performed on 10 CM chondrites using petrographic and scanning electron microscopy.

Results and Discussion:

Some of the most prominent alteration textures and mineral associations in CM chondrites are very likely to have formed in a quiescent asteroidal environment. For example, terrestrial studies have demonstrated that pseudomorphic structures are one of the most diagnostic indicators of an unenergetic alteration environment [3]. Our analysis reveals that a significant fraction of the matrix material in many CM samples is made up of well-defined pseudomorphic structures that fully replace chondrules, CAIs, and their fragments. Similarly, many of the rim materials surrounding isolated matrix olivines and pyroxenes, whose formation has been previously attributed to nebular processes [4], display clear evidence of having formed by incomplete pseudomorphic replacement [5].

A variety of alteration textures and minerals are fragile, and it is unlikely that these would have been preserved during energetic impact-mixing events [5]. For example, two or more chondrule rims are often joined by delicate extensions of rim material that also display lacy intergrowth patterns with the surrounding matrix. Also, the rind materials that surround some matrix silicates gradually dissipate into, and eventually become indistinguishable from, the surrounding matrix. These gradational rind textures, some of which are several mm thick, likely formed by diffusive processes in an aqueous medium and would have been readily disrupted by even gentle impact-related mixing events. We also note that calcite is a notoriously soft mineral that fractures very easily to form well-defined rhombohedra, yet rhombohedral carbonate grains are rare or absent in CM chondrites.

A large proportion of the matrix olivine, pyroxene, and carbonate grains in CM matrices are surrounded by thin rims or "rinds" of phyllosilicates and S-bearing phases. Therefore, these rind textures must have formed after the core grains that they surround. If matrix olivine and pyroxene grains are indeed fragments of impact-disrupted chondrules and CAIs [6,7], then the rinds around them must have formed after the major chondrule fragmentation process was complete. Similarly, if accretionary or impact-related processes had at one time disrupted CM carbonates to form rhombohedral fragments, then aqueous reactions must have subsequently overprinted any evidence of these events. In fact, all the observations described above strongly suggest that brecciation occurred before the aqueous processing of CM chondrites was complete.

Because the petrologic features described above would also have been destroyed by energetic impact-related events that occurred *after* aqueous processing was complete, it follows that pervasive mixing could not have occurred during subsequent lithification and compaction events either. All the samples examined in this study show evidence of gentle compaction, which has been documented by the use of rosetta diagrams. Elongated tochilinite and phyllosilicate grains, products of aqueous reactions, display preferential alignment to varying degrees in the individual samples. This is consistent with the hypothesis that CM chondrites sample the interior portions of asteroids, rather than an outer mechanically-mixed regolith layer. Such gentle compaction could have been caused at depth by either overburden pressures or by dampened impact forces.

There are several interesting implications of the petrologic interpretations presented here. For example, ^{26}Al-based thermal models constrain the heat source needed for the aqueous processing of CM chondrites to time scales of ~ 10^5 - 107 years [2]. If CM alteration occurred after brecciation was complete, as suggested here, then brecciation must have also occurred within ~ 10^7 years. This is consistent with models for rapid accretion and short periods of regolith activity [8,9], with early compaction ages (4.4 b.y. ago or earlier) predicted for several CM samples [10], and with the early post-brecciation alteration history inferred from isotopic studies for CI chondrites [11]. However, it does not agree with long periods of pre-compaction regolith exposure that are suggested by the irradiation data for some CM chondrites [12, and refs. therein] or petrologic models that describe the pre-accretionary alteration of CM chondrites [4]. An alternative explanation for the irradiation data [12] that is consistent with the ideas presented here is that CM materials were subjected to an enhanced particle flux in the early solar system, but the location of CM alteration is unresolved. A model that satisfactorily describes the formation of CM chondrites needs to explain all the observations presented here, in addition to the other data.

References: [1] Hohenberg et al. (1990) *GCA*, 54, 2133-2140. [2] Grimm and McSween (1989) *Icarus*, 82, 244-280. [3] Wicks and Whittaker (1977) *Can. Min.*, 15, 459-488. [4] Metzler et al. (1992) *GCA*, 56, 2873-2897. [5] Browning et al. (1997) *GCA*, submitted. [6] McSween (1977) GCA, 41, 1145-1161. [7] Richardson and McSween (1978) *EPSL*, 37, 485-491. [8] Housen and Wilkening (1982) Ann. Rev. Earth Planet. Sci., 10, 355-376. [9] Housen et al. (1979] Icarus, 39, 317-351. [10] MacDougall and Kothari (1976) *EPSL*, 33, 36-44. [11] MacDougall and Lugmair (1989) *Meteoritics*, 24, 297. [12] Hohenburg et al. (1990) *GCA*, 54, 2133-2140.